capacity, must deal with capacity limitations in shared use.[20] The way that the capacity need is dealt with in a particular situation depends ultimately upon subscriber demand in a given area. Initially, cells will be fairly large as demand is low at PCS introduction stage. It is in this stage that the capacity gain from ISCDMA is of greatest use. Cells that are several miles across (and cells this size could be easily served by CDMA) might have several microwave paths at differing frequencies crossing different parts of the cell. Rather than exclude all channels which might interfere with the fixed microwave transmissions at any part of the cell, ISCDMA allows channels unusable in certain parts of the cell to be used in other parts of the cell, for an overall capacity gain in the cell. This reduces capital cost (the need to introduce additional cells/base stations to serve subscribers). This in turn results in lower cost to subscribers.

When subscriber demand grows further in a given area, channel splitting (smaller cells) is in order. One advantage of CDMA is that with a small cell, base station power (and summed power on a given transmission channel) will be reduced, allowing channels previously interference blocked in the larger, higher power cell to become useable. ISCDMA would automatically adjust for this through the scanning process. Also, of course, there is an automatic, and with CDMA substantial, capacity gain in the area resulting from frequency repeat with smaller CDMA cells.

In areas which are severely impacted by fixed microwave, smaller cells might have to be introduced at the outset to provide needed capacity on the limited number of frequencies in the area free from fixed microwave interference. In other words, cell size will be determined by a combination of subscriber demand and the extent of fixed microwave interference in an area.

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[20]This is particularly true if, as CTP advocates, multiple PCS operators are licensed by the FCC in each geography. In this connection, one of the advantages of narrow channel CDMA is that it allows multiple PCS operators either to co-exist through having separate frequency allocations in the 1850 - 1990 MHz band or to co-exist based on relative demand. Co-existence based on demand would mean that all operators could dynamically share the same frequency (1850 - 1990 MHz), an approach eminently workable with ISCDMA. Indeed this may be a fairer approach in a fixed microwave environment as "hard" frequency allocation might result in unfair treatment of some operators in some geographies where their particular block of frequency happens to be more impacted by fixed microwave than the frequency blocks of other operators.

Finally, there might be a very few areas so severely impacted by fixed microwave in the 1850 - 1990 MHz band that no free channels exist for ISCDMA. Certainly this could be true for a TDMA approach, particularly a TDMA approach using exclusion zones. However, this same cell using CDMA and using the spectrum spreading capability of CDMA to reduce interference to fixed microwave, and operating at low power both because of use of CDMA and small cell size, should have channels available for ISCDMA.

Thus CTP questions that in any given geography in the country (a microwave "hot spot") it will be found that microwave users are so closely packed in geography and frequency that it will be impossible to find non-interfering room for at least a few low power, 1.228 MHz CDMA channels. The experience of Cellular Data, Inc., a company of which Lockton of CTP was Chairman, bears this out. Lockton, while at Cellular Data helped develop a technology which inserts narrow channel data transmission at 2400 bps into cellular radio frequencies without interfering with cellular voice transmissions. The technology works successfully in the most densely packed and sectorized cellular systems in the U.S., and is now well known to the FCC and the cellular industry. At the time the technology was developed (Fall 1987) there was substantial industry doubt narrow channel transmission could be inserted into cellular without interference, but testing proved the viability of the approach. So, too, testing will be needed of ISCDMA in microwave transmission hot spots to convince doubters.[21]

It should be noted that while ISCDMA will add capacity in areas with substantial fixed microwave transmission by increasing the number of useable channels, the previously discussed advantages of regulatory certainty and certainty of protection of fixed microwave users remain perhaps even more important. <u>The more microwave in an area, and the more complicated the layout of microwave frequency use and microwave paths in an area, the more an approach which automatically adjusts to avoid microwave interference makes sense</u>. This is why ISCDMA was developed.

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[21]If testing proves that in microwave transmission hot spots even ISCDMA does not find useable channels, CTP would not recommend near term relocation of the microwave users. The number of such hot spots will be so few using ISCDMA that it is far better to have PCS operators work around them than to have to deal with fixed microwave user opposition to PCS and consequent possible delay of introduction of PCS.

Conclusion. In its pioneer's preference request QUALCOMM refers to the interference testing it is starting to perform and states: "The information gathered in the field trials being conducted by QUALCOMM will provide the basis for implementing software changes to the basic CDMA system so that 'co-existence' criteria can be used in PCS operations." CTP feels that these software changes will be few and can be quickly accomplished. Subscriber terminal receiver sensitivity to pilot channel degradation must be tested to ensure that subscriber terminals will not operate on transmission channels which might cause microwave interference. Pilot channel interference sensing in a high demand cell must be demonstrated. Finally, the capability of ISCDMA in microwave interference "hot spots" must be established. It is CTP's belief that all of this can be accomplished to Commission satisfaction in relatively short order, allowing rapid deployment of ISCDMA throughout the U.S.[22]

[22]In this regard CTP notes that many applicants are proposing narrow channel CDMA in various parts of the country, particularly QUALCOMM's technology. CTP very much welcomes this. CTP believes these applicants can and will work together to create national roaming for narrow channel CDMA, and eventually an integrated system across most of the U.S. In this connection, CTP particularly supports the activities of Telemarc Telecommunications, Inc. which is working to create a national network of PCS operators using QUALCOMM technology.

QUALCOMM INCORPORATED

Types of Handoff

- Idle handoff
  - When receiving the Paging Channel
- Soft handoff
  - Operate with multiple base stations
  - Make before break operation
- Hard handoff
  - Between CDMA frequency assignments
  - On the same CDMA frequency assignment (intersystem handoff)
- CDMA to analog handoff

Idle Handoff Steps

- Mobile station searcher reports that new base station pilot level has exceeded old base station level by a certain amount for some time
- Mobile station assigns fingers to the new base station
- Mobile station uses NGHBR_CONFIG field to determine what to do
  - Just slide to using same Paging Channel and CDMA frequency
  - Go to Primary CDMA frequency assignment and use Primary Paging Channel
  - Use Primary Paging Channel on first CDMA frequency assignment in CDMA Channel List Message
  - Acquire Sync Channel on the Primary CDMA frequency assignment
- If previously received base station, checks overhead sequence numbers
  - If not changed, slotted mobile station goes to sleep
  - If changed, stays awake to receive overhead messages
- Minimizes
  - The amount of time not receiving the Paging Channel
  - Power consumption

Soft Handoff Steps
(Normal Operation)

- **Mobile station searcher reports that new base station pilot has exceeded T_ADD**
- **Mobile station reports this in a *Pilot Strength Measurement Message***
- **Base station sends *Handoff Direction Message* putting mobile station in soft handoff**
- **Mobile station assigns fingers to receive both old and new base stations**
- **Mobile station searcher reports that old base station pilot has dropped below T_DROP**
- **Mobile station reports this in a *Pilot Strength Measurement Message***
- **Base station sends *Handoff Direction Message* taking mobile station out of soft handoff**

EXHIBIT C

Co-Existence of Personal Communication Systems with Fixed Operational Microwave Links Using Interference Sensing Code Division Multiple Access (ISCDMA) Technology

submitted to

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1.0 Abstract

An approach to Personal Communication Systems (PCS) through use of the interference sensing capabilities of CDMA pilot channels plus all of CDMA paging channels is discussed in this paper. The validity of the theory of providing interference protection for fixed microwave users through ISCDMA while maintaining a good communication quality in the ISCDMA system is also demonstrated.

2.0 Introduction

Interference Sensing Code Division Multiple Access (ISCDMA) is a method that combines an interference sensing approach and spread spectrum techniques to solve the co-existence problem of Personal Communication Systems (PCS) and existing fixed microwave links. Various investigations by different companies and research groups [1], [2], [3] have shown that there is enough spectrum for initial operation of PCS without reallocating fixed microwave links to other frequencies. One important difference between the ISCDMA technology and approaches proposed by other companies is that ISCDMA will actively provide interference protection for fixed microwave users while other approaches depend passively on the careful engineering of the exclusion zone. Moreover, if ISCDMA is employed for PCS systems, the portable handset can be designed for use in any city in the country. Therefore, ISCDMA demonstrates great potential to be used in emerging Personal Communication Systems. In order to show ISCDMA technology is feasible to implement, the protection of interference from the PCS system to fixed microwave users must be guaranteed. Analysis that describes a way to provide such protection using CDMA pilot channels and paging channels is presented in this paper.

Equipment implementing Qualcomm's direct sequence code division multiple access technology (DSCDMA) is assumed in our analysis. Frequency division is employed by dividing the available spectrum into nominal 1.228 MHz wide channels[4]. Qualcomm's technology provides four different sub-channels in each 1.23 MHz wide forward channel[4]. They are traffic channels, the synchronization channel, paging channels and the pilot channel. The pilot channel is used by the mobile to identify the base station which provides the best signal (that is the strongest and the lowest bit-error signal) at the mobile. The pilot channel is also used in power control in both directions and phase tracking, as well as for power allocation in the forward link[5]. As explained subsequently, the pilot channel can also be readily used in the ISCDMA system for interference sensing. In fact, very little modification of the Qualcomm technology is required for ISCDMA to apply. Coherent detection and non-coherent detection are used at the mobile and at the base station respectively. More specifications on Qualcomm DSCDMA can be found in references [4], [5] and other Qualcomm publications.

Most standard fixed operational microwave links have the transmit and receive frequency offset by 80MHz[2]. While reference [2] shows that some non-standard microwave links[1] exist in some cities, research in [2] finds that the highest number of non-standard microwave links found in any of the eleven largest U.S. cellular markets is only 6[2]. Therefore, we concentrate on a feasibility analysis for an ISCDMA system for the standard two-way transmission microwave links. In Section 3.0, the interference level from a single PCS two-way transmission link to a single microwave link is presented. This analysis is then expanded into the general multi-base stations/mobiles in Section 3.1. Interference sensing using pilot channels and paging channels for the ISCDMA system is demonstrated in Section 3.2. Both references [1] and [2] show that more than one microwave link operating at the same frequencies[3] in different part of a city is common. The effects of multiple microwave links using the same frequencies on the ISCDMA system is presented in Section 4.0.

3.0 Two-Way Transmission Microwave Link with one base station and one mobile

Figure 1 shows a general interference situation between the PCS system and fixed microwave stations. In the figure, BS represents a PCS base station and MICRO represents a microwave tower. In general, there will be more than one microwave link and more than one base station and mobile in the market. In this section, we will study the coupling of energy between the microwave link and the PCS system with the most simple form, i.e. a single two-way transmission link in each system. We can then expand the analysis to more general cases.

In the figure, microwave station A transmits frequency f1 and receives frequency f2 while microwave station B transmits frequency f2 and receives frequency f1. For the PCS system, the base station transmits frequency f1 and receives frequency f2 while the

1. either simplex or not following standard channel plan

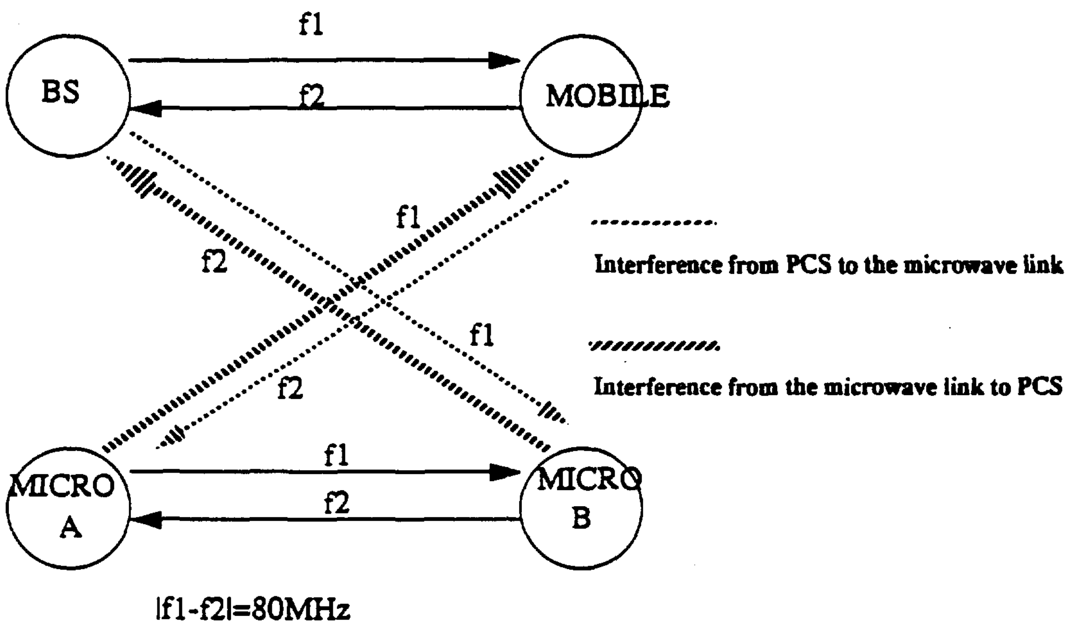
2. Los Angeles

3. reverse channel and forward channel

mobile transmits frequency f2 and receives frequency f1[4]. Four sources of interference between the PCS system and the microwave link are possible.

- Interference from Microwave Station A to the mobile $I_{A/mobile}$
- Interference from Microwave Station B to the base station $I_{B/BS}$
- Interference from the mobile to Microwave Station A $I_{mobile/A}$
- Interference from the base station to Microwave Station B $I_{BS/B}$

FIGURE 1. Mutual Interference of Microwave Link (two way transmission) and PCS system



If there are more than one base station and more than one mobile in the system, there will be additional interference to the microwave link as well as within the PCS system. This will be discussed later. For the present discussion, we assume there are only one mobile and one base station in the PCS system. For the ISCDMA system, the base station can scan the entire frequency band and measure the interference power from the microwave station B[5], $I_{B/BS}$, and if the maximum transmitter power of the microwave

4. Alternatively, the base station can transmit frequency f2 and receive frequency f1 while the mobile transmits frequency f1 and receives frequency f2. In order to provide maximum isolation between the PCS system and the microwave link, the base station and the mobile should transmit at frequencies that have minimum mutual interference between the PCS system and microwave users. In Figure 1, we assume that $I_{A/BS}$ is larger than $I_{B/BS}$.

5. The base station also measures the interference from the microwave station A. For the above discussion, we assume $I_{B/BS}$ is smaller than $I_{A/BS}$ and therefore the base station decides to transmit frequency f1 rather than frequency f2.

station B is known, then the path loss from microwave station B to the base station can be calculated from the measured signal level from the microwave tower.

$$I_{B/BS}(dB) = Pt(B) - PL_{B/BS} + G_B + G_{BS} \quad \text{(EQ 1)}$$

where $Pt(B)$ is the power transmitted by microwave station B, $PL_{B/BS}$ is the measured path loss from microwave station B to the base station. G_B, G_{BS} are the antenna gains of microwave station B, and the base station respectively. It should be noted that $I_{B/BS}$ is based on the known characteristics of the microwave transmitter and is a static quantity, subject to small changes due to measured signal strength.

If PCS channels are assumed to be reciprocal[6] and f1/f2 is close to unity, then the path loss from the microwave station B to the base station is virtually the same as that from the base station to the microwave station B. If the transmitter power of the base station is known, the corresponding average interference power from the base station to the microwave station is given by:

$$I_{BS/B}(dB) = I_{B/BS} - Pt(B) + Pt(BS) \quad \text{(EQ 2)}$$

where $Pt(BS)$ is the power transmitted by the base station.

It is desirable to have the interference power level from the PCS system to the microwave links to be small. One standard is that the interference power should be 6 dB below the thermal noise level[7]. The maximum interference threshold is denoted as Th. In order to protect the microwave link from interference caused by the PCS system, the following inequality must be satisfied.

$$I_{B/BS}(dB) \le Th + Pt(B) - Pt(BS) \quad \text{(EQ 3)}$$

If the base station determines that equation (3) is satisfied, it can transmit frequency f1 without interfering with microwave station B. This information can then be sent to the mobile via the paging channel. The mobile then needs to determine whether the interference from microwave station A is small enough to protect microwave station A from interference while maintaining a good communication quality in the PCS system. The figure of merit for determining the quality of transmission of a CDMA signal is the bit energy to noise density ratio (Eb/No). Eb/No at the mobile is given by:

6. It is well known that path loss in mobile propagation channels is characterized by a log-normal large scale path loss superimposed by a small scale Rayleigh fading[10]. While large scale path loss is not sensitive to small frequency change, small scale fading is extremely sensitive to frequency change because it is primarily a phenomenon of superposition of multipath components with different amplitudes and phases, which can change significantly even if frequency changes by little. However, references [8] and [9] show that rms delay spread in microcellular propagation environment varies from a few hundred nanoseconds to a few microseconds, depending on the location, the T-R separation and other factors. Assuming a rms delay spread value of 500 ns, which corresponds to a coherence bandwidth of 200kHz[10], a 1.25 MHz bandwidth can therefore offer frequency diversity. Thus, it is justified that the path loss is reciprocal between the base station and the microwave station although frequencies are offset by 80MHz.

$$\left(\frac{E_b}{N_o}\right)_{mobile} = \frac{Pr_{mobile}/R}{(I_{A/mobile} + \eta)/W} = \frac{Pr_{mobile} \bullet PG}{I_{A/mobile} + \eta} \quad \text{(EQ 4)}$$

where PG is the processing gain[7], Pr_{mobile} is the power of the desired signal received at the mobile which is a function of transmitter power of the base station, location of the mobile, and the propagation model, and η is thermal noise power[8]. It is clear from equation (4) that if $I_{A/mobile}$ is much larger than Pr_{mobile}, the communication quality at the mobile may not be acceptable.

The interference power $I_{A/mobile}$ is measured at the mobile. The methodology to measure $I_{A/mobile}$ by pilot channels will be presented in section 3.2. Similar to the above derivation, microwave station A is protected from interference caused by the PCS system if the following inequality is satisfied.

$$I_{A/mobile}(dB) \leq Th + Pt(A) - Pt(mobile) \quad \text{(EQ 5)}$$

Equations (3) and (5) guarantee protection of microwave users from the PCS interference. The measured interference powers from the microwave station B to the base station and from the microwave station A to the mobile are used in equations (3) and (5) to determine if the interference from the PCS system to the microwave link is below threshold Th or not.

Horizontal polarization is used for half of microwave links [3] while vertical polarization is likely to be used in PCS systems. The polarization mismatch of the two systems can provide an extra protection for microwave users. However, we cannot rely on polarization to provide sufficient isolation between the two systems because depolarization of electromagnetic waves in a non-line-of-sight channel is generally high. If channels are assumed to be reciprocal, equations (2) to (5) can be applied without modification to include polarization effects.

3.1 Multiple Base Stations and Multiple Mobiles

If there are more than one mobile and more than one base station transmitting frequency f1 and receiving frequency f2 in the area of interest, then the interference power from the PCS system to the microwave system will definitely be higher than obtaining in the single base station/single mobile case. The interference level within the PCS system will be higher as well. The summed power of the transmission at the base station can increase as subscriber demand increases, causing increasing interference to the microwave users, whereas this could not occur in "normal" demand load operation. The interaction between multiple base stations with multiple mobiles and a single two-way microwave

7. Bit rate of 8kb/s is that of an acceptable toll quality vocoder which gives processing gain, PG, to be equal to 154 [4].

8. Thermal noise power is equal to the thermal noise spectral density (η_o) multiplied by the total spreading bandwidth W.

link is considered in this section. By repeating the same argument for different microwave links, the capacity and performance of the ISCDMA system can be obtained.

Assume there are N mobiles that transmit frequency f2 and receive f1 within the area of interest, and there are M base stations in the area. The total interference power (in linear scale) from the PCS to the microwave station A, $I_{PCS/A}$, can be given by:

$$I_{PCS/A} = \left(\sum_{i=1}^{N} \frac{I_{A/M_i} Pt(M_i)}{Pt(A)}\right) \frac{BW}{1.23} \le Th \qquad \text{(EQ 6)}$$

where $I_{A/Mi}$ is interference power from the microwave station A to the i-th mobile and $Pt(M_i)$ is the power transmitted by the i-th mobile. It should be noted that the interference to the microwave station should be multiplied by a factor[9] of $BW/1.23$ where BW is the operating bandwidth(MHz) of the microwave station A and 1.23 denotes the bandwidth of the Qualcomm CDMA signal.

Similarly, the total interference (in linear scale) from the PCS system to the microwave station B, $I_{PCS/B}$, is as follows.

$$I_{PCS/B} = \left(\sum_{i=1}^{M} \frac{I_{B/BS_i} Pt(BS_i)}{Pt(B)}\right) \frac{BW}{1.23} \le Th \qquad \text{(EQ 7)}$$

where $I_{B/BSi}$ is the interference power from the microwave station B to the i-th base station and $Pt(BS_i)$ is the power transmitted by the i-th base station[10]. Interference power from the microwave station B to each base station can be measured prior to the operation of the PCS system or can be performed on a regular basis. Therefore, to keep track of the total interference from PCS system to the microwave link, there must be stored in each base station the interference power from microwave station B to each base station, the transmitter power of the microwave station and its operating bandwidth. Also, the difference between Th and $I_{PCS/A}$ as well as the difference between Th and $I_{PCS/B}$ should always be *larger* than zero in order to not interfere with microwave station A and B. Finally, the difference between Th and $I_{PCS/A}$ should be passed to the mobile over the paging channels to allow computation of interference from mobile units. Additional means for keeping track of the total interference from the PCS to the microwave link will be presented in the next section.

Hence, in order to provide protection for the microwave system, $I_{PCS/A}$ and $I_{PCS/B}$ must be less than the required threshold. Every time a new call setup is requested, the

9. There is more than one CDMA reverse channel within the operating bandwidth of microwave station A. The total interference power from the PCS system to the microwave station A includes interference power from all reverse channels within the operating bandwidth of the microwave station A. In equation (6), we assume the interference power caused by each reverse channel is the same.

10. $Pt(BS_i)$ is the power transmitted by the base station i for one forward channel only. In equation (7), we assume $Pt(BS_i)$ for forward channels within the operating bandwidth of the microwave station B are the same.

interference power from the PCS system to the microwave link must be calculated and ensure it is lower than the threshold. Similarly, every time a call is completed, the interference power must be updated as well. However, these two inequalities[11] are not alone sufficient to ensure frequencies f1 and f2 are good for operation within the PCS system because interference power from the microwave link to the PCS system may be too high for the PCS system to have a good communication quality. Consider the reverse link again (from the mobile to the base station). If perfect power control is assumed in the reverse link, then the bit energy to the noise density level[12] at the base station *j*, $(Eb/No)_{BSj}$, is given by[13]:

$$\left(\frac{E_b}{N_o}\right)_{BS_j} = \frac{P_{R_j} \bullet PG}{(N'-1)P_{R_j} + I_{B/BS_j} + I_{out} + \eta} \leq \left(\frac{E_b}{N_o}\right)_{system} \qquad \text{(EQ 8)}$$

where N' is the number of mobiles within the cell of interest, PG is the processing gain, I_{out} is interference power due to mobiles that are outside the cell, $(Eb/No)_{system}$[14] is the minimum system performance required, and P_{Rj} is the power received at the base station *j* due to each mobile with prefect power control. The ratio between the in-cell noise to total received noise, not including the microwave interference power, is known as the frequency re-use factor[6]. Some analysis of the frequency re-use factor is presented in [6]. However, the results of [6] are not directly applicable to the case here because a uniform distribution of users was assumed in [6] while there should be more users far away from the microwave link in order to maximize capacity of the ISCDMA system. If the power received at the base station due to each mobile within the cell, the maximum allowable transmitter power by each base station,[15] and the interference power from microwave station B are known, then the maximum allowable users in each cell[16] can be computed from equation (8).

If P_{Rj} is very large compared to $I_{B/BSj}$, then the effect of interference from the microwave station B to the PCS system on the bit energy to noise density ratio at the base station can be ignored. However, increasing P_{Rj} will increase interference on microwave station A due to the mobile since P_{Rj} and $Pt(M_i)$ are related by the following equation:

$$P_{R_j}(dB) = Pt(M_i) - PL_i \qquad \text{(EQ 9)}$$

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11. $I_{PCS/A} \leq Th \qquad I_{PCS/B} \leq Th$

12. The bit error rate (BER) performance, which can be measured at the base station and the mobile, is a function of (Eb/No). By measuring BER, we can obtain the value of (Eb/No) if the modulation characteristics are known.

13. Voice activity gain and sectorization gain are ignored to simplify analysis

14. 5dB to 7dB according to reference [5]

15. The maximum allowable transmitter power depends on the interference power from the microwave station B to that base station. A way to compute the maximum allowable power is presented in the next section.

16. The maximum allowable users in each cell should be different. Cells far away from the microwave link should allow more users than cells close to the microwave link.

where PL_i is the propagation loss (absorbing antenna gains) between the i-th mobile (i=1,2, .. , N') and base station j. An appropriate value of P_{Rj} can be computed such that the interference on the microwave link is tolerable while the capacity of the system is maximized.

Equation (8) ensures the signal quality at the base station (reverse link) is better than the minimum tolerable quality and together with equation (6) confirms frequency f2 at the reverse link will not cause excessive interference to the microwave station A while maintaining acceptable transmission quality.

If interference sensing through pilot channels is to give sufficient protection for the microwave link, pilot channels must become unusable at a threshold where the microwave link is guaranteed no detectable interference will occur to the fixed microwave link. Furthermore, the *Eb/No* value of the pilot channel should be above a certain level in order to maintain a good transmission quality for the forward link. This particular level will be studied as follows. First, the *Eb/No* ratio of the pilot channel of base station i at the j-th mobile, $(Eb/No)_{pilot\ i,j}$, is lower bounded by[5]:

$$\left(\frac{E_b}{N_o}\right)_{pilot_{i,j}} \geq \frac{(1-\beta)\,Pr_{i,j} \bullet PG}{\left(\sum_{i=1}^{M} Pr_{i,j}\right) + I_{A/M_j} + \eta} \qquad \text{(EQ 10)}$$

where β is the amount of power devoted to the subscribers (1-β devoted to the pilot) and $Pr_{i,j}$ is the power received at the j-th mobile due to the i-th (i=1,2, ..,M) base station.

The *Eb/No* ratio of the information bearing channel at the j-th mobile communicating with the i-th base station is lower bounded by:

$$\left(\frac{E_b}{N_o}\right)_{mobile_{i,j}} \geq \frac{\beta\Phi Pr_{i,j} \bullet PG}{\left(\sum_{i=1}^{M} Pr_{i,j}\right) + I_{A/M_j} + \eta} \geq \left(\frac{E_b}{N_o}\right)_{system} \qquad \text{(EQ 11)}$$

where Φ is the portion of the power devoted to the subscriber of interest. Combining equations (10) and (11), we have the following ratio:

$$\frac{(E_b/N_o)_{pilot_{i,j}}}{(E_b/N_o)_{mobile_{i,j}}} = \frac{1-\beta}{\beta\Phi} \qquad \text{(EQ 12)}$$

Equation (12) relates the bit energy to noise density ratio of the pilot channel to that of the forward traffic channel. Hence, a threshold that incorporates equation (12) can be designed at the mobile to reject an unusable forward channel. The mobile receiver scans through all pilot channels. If the first pilot channel has low power or exhibits bit error transmission problems, the subscriber terminal continues the scan until it finds a pilot channel with strong power and low bit error rate. However, these are not sufficient criteria for selection of the traffic channel because the interference from the PCS system to the microwave link may be high. Equations (6), (7), (8) and (11) must be satisfied *simultaneously* if a frequency pair f1/f2 is functional in the PCS system while the interference to the microwave station is tolerable. The pilot channel and paging channel are used to satisfy these four requirements as will be discussed in the next section.

3.2 Interference Sensing by Pilot Channels

The criteria for determination of "tolerable" interference caused by PCS on microwave users have been presented in the last section (equations 6&7). The transmission quality at the mobile and at the base station have been explained (equations 8&11). Four criteria must be satisfied if a duplex CDMA channel is to be deemed *usable* for communication between the base station and the mobile:

- total interference from PCS to the microwave station A is below threshold
- total interference from PCS to the microwave station B is below threshold
- transmission quality of the forward link of PCS is above a particular performance level
- transmission quality of the reverse link of PCS is above a particular performance level

First consider the forward link, i.e. from the base station to the mobile. We have demonstrated that the total interference from the PCS system to the microwave station B is given by equation (7). Therefore, if interference caused by each base station on the microwave station B is less than *Th*/*M*, where *M* is the total number of base stations, then the total interference from the PCS system to the microwave station B is less than threshold and satisfies the second criterion above. If the maximum allowable power at a particular base station is less than the minimum power to set-up a traffic channel[17], then the forward channel is considered *unusable* in that cell. Suppose the channel is unusable for the forward link in L cells[18], the maximum allowable transmitter power[19] by each base station is given by:

$$Pt(BS_i) \leq \frac{ThPt(B)}{(M-L)\,I_{B/BS_i}} \qquad \text{(EQ 13)}$$

The maximum allowable transmitter power of the base station is large if the interference caused by microwave station B onto that base station is small, and vice versa. The total allowable transmitter power includes power for all forward channels, i.e., traffic channels, pilot channels, synchronization channels and paging channels, that are within the operating bandwidth of the microwave link. Equation (13) provides one way to divide the allowable transmitter power of base stations by making interference powers from each

17. The minimum power to set-up a traffic channel includes power for each of the pilot channel, the synchronization channel, the paging channel, and the traffic channel.[4]

18. L, $I_{B/BSi}$ are fixed quantities

19. Include power of all forward channels within the operating bandwidth of microwave station B of each base station

base station to the microwave station B the same. If there are high demands in one particular cell, the allowable transmitter power of the base station can be increased by decreasing the maximum allowable power in cells with less demand. The total interference power on the microwave station is below the specified threshold as long as equation (7) is satisfied.

Each base station needs to follow two steps to determine if the forward traffic channel, with an additional mobile, is still usable or not. As a first step, the base station should estimate the total interference on the microwave station B if an additional mobile is put into the cell. If the total interference of the forward link on microwave station B (which is increased by an extra mobile in the cell) is still below the threshold and the additional user does not cause a degradation of transmission quality of the reverse link to be below a certain performance level, then the forward traffic channel, with an additional mobile, is still usable. If one or both conditions are violated, the base station should indicate to the mobile[20] that the forward traffic channel is not available. To sum up, the following two criterion must be satisfied simultaneously if the forward traffic channel, with an additional mobile, is to be usable.

- the total interference by the forward link of the PCS system onto the microwave station B, with the additional interference caused by the extra user, is still within the required threshold
- the transmission quality of the reverse link, with the additional mobile, will be above the specified performance level

The first condition mentioned above can be checked by equation (7) while the second condition can be checked by equation (8). Two remaining criteria must be checked at the mobile.

The interference caused by the microwave station A on the mobile is estimated via the quality of pilot channels. Signals from different base stations are distinguished by pseudo-random noise (PN) code with different time offsets[4]. The mobile unit acquires the strongest pilot by searching (correlating) all 32768 time shifts of the PN code. Based on these measurements, there are M+1 unknowns, P_{r1}, P_{r2}, ..., P_{rM}, and $I_{A/M}$. Since there are more than M+1 equations with M+1 unknowns, $I_{A/M}$ can be determined uniquely. It can be shown that the solution is quite simple[21]. Assuming $I_{A/M}$ is known based on these measurements at the mobile, the mobile then can determine if equation (6) is satisfied[22], with the additional mobile. If equation (6) is satisfied, then criterion number one at the beginning of this section is satisfied. Next, the mobile needs to check if the *Eb/No* of the information bearing channel is above the specified threshold or not. This can be done by applying equation (12) which relates the bit energy to noise density ratio of the

20. One way to do this is to embed the information into the paging channel.

21. Numerical methods such as Gaussian Elimination are not needed. The exact algorithm to determine interference from microwave users to PCS depends on the specific parameters of pilot channel strength measurement which are proprietary to Qualcomm.

22. The original value of interference power from mobiles (without the additional mobile) to the microwave station A can be passed to the new mobile via the paging channel.

pilot channel to that of the forward traffic channel. Figure 2 gives a simple algorithm which explains how the above procedures can be implemented at base stations and mobiles. A microprocessor that performs all the above computations can be designed and implemented at the mobile unit[23]. Equation (6) requires knowledge of the transmitter power of microwave station A, its bandwidth and the original interference power from PCS to the microwave station A (without the additional mobile). This information can be obtained from the base station via the paging channel. However, this introduces complexity in the mobile unit. An easier way which allows the mobile unit to provide interference protection for microwave station A is through threshold design into the mobile unit. If a worst case design is used, no information needs to be transmitted from the base station to the mobile unit. Methodology of a worst case design is presented in the next section.

3.2.1 Worst Case Interference Threshold Design

There are two types of interference experienced by a mobile unit: interference from neighboring base stations and interference from the microwave station A. Therefore, it is *impossible* to compute actual interference power due to microwave station A based on a single pilot quality (strongest pilot) measurement[24]. However, it is possible to provide an upper bound of interference power from the microwave station A to PCS by assuming microwave station A being the only source of interference and in turn set a threshold for interference power from mobile units to microwave station A. This solution trades simplicity in the mobile unit for a certain loss of capacity. Assuming for the purpose of setting the necessary interference threshold that all interference received by PCS mobile units is caused by microwave station A, interference from microwave station A to PCS should not exceed the worst case interference threshold, *Th_Interference*, in order to provide interference protection for microwave users. If the interference power from mobiles to the microwave station A is divided equally among each mobile, then the worst case interference threshold is given by:

$$I_{A/M_i} \le \frac{ThPt(A)_{min}}{N_{max} Pt(M_i)_{max} \gamma_{max}} = Th\_\ interference \qquad \text{(EQ 14)}$$

where γ_{max} is maximum value of BW/1.23, $Pt(A)_{min}$ is the minimum transmitter power used by microwave station A, $Pt(M_i)_{max}$ is the maximum transmitter power of the mobile unit and N_{max} is the maximum number of mobiles in the PCS system. Therefore, the right hand side of equation (14) provides a worst case (minimum) interference threshold. Interference from microwave station A to the mobile, $I_{A/Mi}$, must not exceed *Th_interference* if the microwave station A is guaranteed interference protection. All parameters in equation (14), except N_{max}, can be found by checking the specifications of microwave stations and mobile units. The main difficulty lies in the setting of N_{max}. If

23. With the advance of microprocessor technology, the above computations can be done easily and economically.

24. Hence, it is not possible to assign a bit-error rate (BER) threshold for the strongest pilot channel such that microwave station A is guaranteed protection.

N_{max} is set very small, the system capacity will be limited. On the other hand, if N_{max} is set too large, the threshold may be too "tight" (i.e., threshold being too small) so that some usable reverse channels are rejected from use. Further study is required to determine an optimum value of N_{max}. Also, the degradation of capacity, using a worst case interference threshold, needs to be studied as well[25]. This will be done through further analysis to be submitted to the Commission.

4.0 Multi-Microwave Links Sharing Same Frequencies

In this section, we expand the analysis of section 3.0 and combine it with the analysis of section 3.1. That is, the single microwave link is generalized to multi-microwave links sharing the same frequencies with multiple base stations/mobiles. However, only the concept rather than the mathematical detail is presented because the equations for this case are very similar to those in the last two sections. Assume there are K microwave links sharing the same frequencies and denote the stations of each link as Ai, Bi for i=1,2,..., K. All the analysis preformed above remains valid if the following steps are followed.

4.1 Estimation of Path Loss Between Each Microwave Link and Each Base Station

The total interference power from microwave users to the base station is a superposition of interference powers from each microwave user sharing the same frequencies. Therefore, the measurement of interference power at the base station is a sum of interference powers from each microwave station. Equation (1) is modified as follows to include effects of multiple microwave stations.

$$I_{MICRO/BS_j} = \sum_{i=1}^{K} \frac{Pt(B_i)}{PL_{B_i/BSj}} \qquad \text{(EQ 15)}$$

where $I_{MICRO/BSj}$ is the interference power from all microwave users to the base station j, $PL_{Bi/BSj}$ is the propagation loss (absorbing antenna gains) from the microwave station Bi to the base station j. It is easy to show that the propagation loss from each microwave station Bi to the base station j is always larger than $Pt(Bi)/I_{MICRO/BSj}$. Therefore, we have a minimum path loss between the base station and each microwave station and the maximum interference power from each base station to each microwave user can be computed. A similar equation can be derived for the propagation loss between each mobile and each microwave station.

25. It is clear that the approach presented in Section 3.2 is more complicated than that of Section 3.2.1. The capacity of the former approach will be higher than that of the latter one. Hence, there is a trade-off between complexity and capacity. If the values of Pt(A) and γ do not vary by much, however, the system capacity using the latter approach will be close to the capacity using the former approach.

4.2 Interference Protection

Interference protection for microwave stations can be achieved by applying (6) and (7) for all the microwave stations. That is, A and B in equations (6) and (7) becomes Ai and Bi, and we need to determine if equations (6) and (7) are satisfied or not for K times.

4.3 PCS Communication Quality

The criteria for good communication quality of the PCS system is the same as before. No matter whether there is one microwave link or there are multiple microwave links sharing the same frequencies, equations (8) and (11) must be satisfied in order to provide the minimum performance level. The only modification in equations (8) and (11) is that the sum of the interference power from multiple microwave stations must appear in the denominator rather than just interference from only a single microwave station.

5.0 Conclusion

We have established criteria for a frequency-division CDMA duplex channel to have tolerable interference to microwave links while maintaining a good communication quality in the PCS system. By measuring interference power at the base station and assuming reciprocity of path loss holds for forward and reverse channels, the interference power to the microwave station can be estimated if its transmitted power is known. The pilot channel as well as the paging channel are used to ensure all the criteria explained in section 3.2 are satisfied simultaneously. At the mobile, the communication quality of the forward link can be estimated by measuring the transmission quality of the pilot channel. If the transmission quality of the pilot channel is above a certain threshold, then the mobile needs to check whether the mobile will cause excessive interference to microwave users. Therefore, the transmit and receive frequencies of microwave links as well as their corresponding transmitter powers and operating bandwidths must be stored at each base station. This information then needs to be sent to the mobile via the paging channel. Alternatively, for simplicity in the mobile unit, a worst case interference threshold can be used to ensure interference protection for microwave users while avoiding transmission of microwave station parameters from the base station to the mobile unit. No interference mapping is required since all interference computations are done autonomously at base stations and mobiles. Also, we have discussed briefly how to expand the model to include the effects of multiple microwave stations sharing the same frequencies. Hence, we have demonstrated how ISCDMA can be used to solve the co-existence problem of the PCS system and fixed operational microwave users. It is clear that ISCDMA is a cost-efficient method since minimum modification of current Qualcomm technology is required and no frequency availability map is needed. Moreover, this approach provides certainty of protection for fixed microwave users, and allows co-primary or even secondary use of the 1850-1990MHz band by a PCS system Therefore, ISCDMA is an efficient and effective spectrum sharing technology for the emerging Personal Communication Systems.

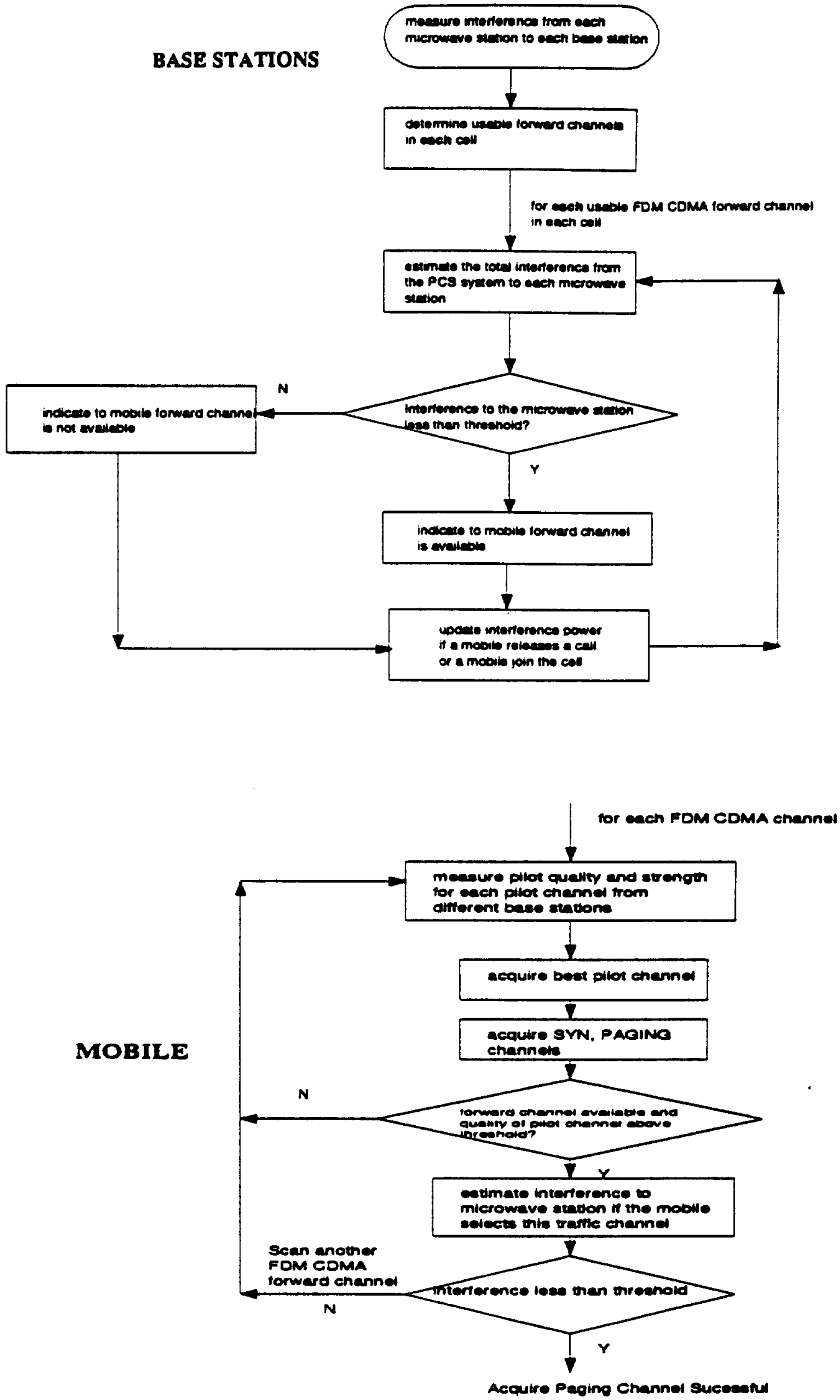

FIGURE 2. Interference Sensing in the ISCDMA system

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BIOGRAPHICAL SKETCH OF THEODORE S. RAPPAPORT (7/92)

Theodore S. Rappaport was born in Brooklyn, NY on November 26, 1960. He received B.S.E.E, M.S.E.E, and Ph.D. degrees from Purdue University in 1982, 1984, and 1987, respectively. In 1988, he joined the Electrical Engineering faculty of Virginia Tech, Blacksburg, where he is an associate professor and director of the Mobile and Portable Radio Research Group. Prof. Rappaport conducts research in mobile radio communication system design and RF propagation prediction through measurements and modeling. He guides a number of graduate and undergraduate students in mobile radio communications, and has authored or coauthored more than 70 technical papers in the areas of mobile radio communications and propagation, vehicular navigation, ionospheric propagation, and wideband communications. He holds a U.S. patent for a wide band antenna and is co-inventor of SIRCIM, an indoor radio channel simulator that has been adopted by over 50 companies and universities. In 1990, he received the Marconi Young Scientist Award for his contributions in indoor radio communications, and was named a National Science Foundation Presidential Faculty Fellow in 1992. He is an active member of the IEEE, and serves as senior editor of the IEEE Journal on Selected Areas in Communications. He is a Registered Professional Engineer in the State of Virginia and is a Fellow of the Radio Club of America. Dr. Rappaport is also president of TSR Technologies, a cellular radio and paging test equipment manufacturer.